Climate and weather uncertainty in the electricity industry

Climate and Weather Uncertainty in the Electricity Industry

S. Parkpoom, G.P. Harrison and J.W. Bialek

Institute for Energy Systems,
School of Engineering & Electronics,
The University of Edinburgh,
King's Buildings, Mayfield Road,
Edinburgh, EH9 3JL,
Scotland, UK

Email: S.Parkpoom@ed.ac.uk
Phone: +44 (0) 131 650 5596
Fax: +44 (0) 131 650 6554

Abstract

The short-term variability of weather patterns and, over the longer term, of climate has a significant impact on the generation, transmission and demand for electricity. Utilities traditionally managed these effects through central planning and vertical integration. In the long term, sufficient plant was planned and constructed to meet anticipated peak demand, whilst the costs of dealing with short-term variability were absorbed and passed on to consumers. With deregulation, the need to manage weather and climate effects has changed dramatically (e.g. imbalance penalties for incorrectly predicted demand). In the longer term, there is a risk that climate change will alter the availability of renewable energy resources, adversely affecting the financial viability of such plant. This paper examines the extent of climatic and weather-related uncertainty affecting the electricity industry and reviews currently available techniques of assessing and managing both short and long term risks.

1. Introduction

Short-term weather variability and, longer term, climate variability has a major impact on the generation, transmission and demand for electricity. Pre-deregulation, utilities generally managed to limit weather and climate impacts through central planning and vertical integration. In the long term, sufficient plant was planned and constructed to meet anticipated peak demand, whilst the costs arising from short-term variability were absorbed and passed on to consumers. With deregulation market participants are becoming exposed to these effects. Hence, there is greater need to manage the impact of weather and climate uncertainty.

Weather is defined as the atmospheric conditions existing over a short period in a particular location. It is often difficult to predict and can vary significantly even over a short period. Climate on the other hand, is generally viewed as the average weather conditions over a long-term period (say 30 years) for a defined area. It varies from place to place, depending on latitude, distance to the sea, etc. Climate also varies in time: seasonally, annually and on a decadal basis. The difference between weather and time can be summed up by "weather tells you what clothes to wear but climate tells you what clothes to buy" [1].

This paper reviews the basis for climate change and the projections for South East Asia. It examines the sensitivity of the electricity supply industry to weather variability and in the longer term to climate change and variability.

2. Climate Change

The state of the Earth's climate is largely affected by heat stored in the atmosphere and oceans. Processes that affect this heat storage can cause the Earth's climate to change. Greenhouse gases (e.g. Carbon Dioxide, CO_2) in the atmosphere tend to trap heat and, whilst changes in levels have occurred naturally over history, it is the extent of man-made greenhouse gas emissions that are causing concern, given the potential to significantly and rapidly alter climate. For the past few hundred years and, particularly from the mid-20th Century, the burning of fossil fuels and deforestation have released increasing quantities of greenhouse gases.

During the last 100 years, global mean temperatures have risen by almost 1ºC with much of the warming in the past few decades. Further increases in man-made greenhouse gas emissions are likely to increase the warming by between 1.4 and 5.8ºC by 2100 [2]. Figure 1 shows the historic and range of projected future temperature rise and clearly shows that the rate of increase has accelerated.

Projections of climate change are often based on the output of General Circulation Models (GCMs), complex numerical models that simulate physical processes in the oceans and atmosphere. There is a wide variation in the output from such models, partly due to the range of input assumptions made. Table 1 shows a sample of scenarios from the IPCC's Special Report on Emission Scenarios (SRES) covering the period of 1990 to 2100 [2]. These include socio-economic estimates (e.g. GDP), the resulting CO_2 levels and the consequent changes in global temperatures and sea levels.

They project changes in a range of climatic variables that have the potential to have significant impacts on a range of sectors in every region.

3. Climate Change in South East Asia

GCM simulations project that the climate in Asia as a whole will undergo an annual mean warming of 3ºC by the 2050s and 5ºC by the 2080s. Accompanying this, an annual mean precipitation increase of 7% and 11% will be seen by the 2050s and 2080s, respectively [5].

The projections for tropical South East Asia are less severe but are still significant, with, for example, mean annual temperature and precipitation rising by some 3% and 8.5%, respectively, by the 2080s [5]. However, these figures mask anticipated seasonal changes. Figure 2 shows the anticipated trend in annual and seasonal temperatures over this century; the greater increase in winter temperatures is clear. Figure 3 shows the corresponding patterns for precipitation which indicate stronger changes in winter precipitation.

Changes of these magnitudes are likely to have significant impacts in South East Asia, given the high population density and low standard of living. It is anticipated that there will be a rising demand for forestry, agriculture and livestock products and it is likely that there will also be an increased risk of fire, typhoons/tropical storms, floods and landslides. Table 2 shows a representative sample of the major climate risks in South East Asia. In addition to these broad risks, there are several impacts that will be felt within the electricity industry.

4. Impacts on Generation

4.1 Thermal power Generation

Thermal generation (i.e. fossil/nuclear powered) could be affected by climate change. Climate variables are known to have an influence on the efficiency of thermal electric generation plants. The basic efficiency of both steam and gas cycles are defined by their Carnot efficiency which is governed by the difference between the hot source (combusted fuel) and cold sink (ambient) temperatures in the thermodynamic cycle. Higher air temperature will raise the temperature of the sink hence decreasing the efficiency and capacity ratings of combustion turbines. Increases in high temperatures and humidity will also be detrimental to electricity generation from gas, oil, or nuclear steam cycles, which rely on cooling towers for the condensing process. In most cases the overall effect of global warming on thermal power production is likely to be small, with one US utility estimating efficiency reductions of between 0.1 and 0.2% [6].

Nuclear power plants might be relatively more sensitive to climate change as they are designed for operation within certain temperature ranges and some plants have been forced to close down on extremely hot days. Climate change might require modification to allow such plants to continue to operate in warmer temperatures [6]. In addition, a climate change induced reduction in river flow could also reduce the efficiency or even require a plant to shut down if inadequate water is available for cooling purposes. Such effects were seen in France in the summer of 2003 when several days of extreme temperatures threatened production from nuclear stations. The overall effect will, of course, depend upon the location of the power plant and the construction techniques used.

Other than efficiency impacts, thermal plant located along rivers or on the coast could be at risk from flooding or sea level rise. There is some evidence that climate change will lead to an increase in cyclone activity and intensity and also monsoon intensity which could pose a threat to plant, particularly on the coast.

4.2 Hydropower

The hydroelectric potential is defined by the river flow, and therefore changes in flow due to climate change will alter the energy potential. Importantly, hydroelectric schemes are designed for a particular river flow distribution, hence; plant operation may become non-optimal under altered flow conditions. Climate change could affect the amount and seasonality of flow in most rivers in South East Asia affecting the magnitude and timing of production.

Hydropower has received the most attention in climate impact studies as it is the widest sued renewable resource and is vulnerable to changes in several climatic variables. Studies reported in [7] examined climate impacts in the Mekong delta (among other international rivers) under a range of potential GCM scenarios. Figure 4 shows the effect of a 5°C degree rise in mean annual temperature accompanied by a 4% rise in precipitation as simulated by the UK Hadley Centre GCM. As can be seen, there are significant increases in several months. While such an increase would appear to be beneficial for hydropower production, the systems ability to harness the increased flows depends on whether sufficient turbine capacity or storage exists.

Changes in river flow and consequently production will have a significant impact on plant revenue stream and ultimately will affect what has been termed ‘willingness to develop’ [8], i.e. investment attraction. A series of studies [9-11] for a planned hydropower scheme in Sub-Saharan Africa examined how climate change could affect the attractiveness of the scheme as an investment. The scheme’s financial viability was shown to be sensitive to changes in precipitation and temperature, that GCM scenarios implied a deterioration in project returns and, that project risk appeared to increase.

4.3 Other Renewable Energy Sources

The potential implications of rising greenhouse gases have increased the interest in energy generated by other renewable sources such as wind power and solar. Currently, South East Asia obtains approximately 80% of its energy from fossil fuels, but many countries have programmers to develop their wind and solar resources. These too will not be immune to climatic effects.

A small but increasing number of studies (e.g. [12]) have considered how wind power would be influenced by global warming. A change in climate might, for example, modify the density and duration of speed wind in a specific area. Large-scale changes in climate zones will also change wind characteristic. However, changes in extreme events such as storms, hail will influence the damage these will have on wind power generation structures and facilities. The impacts of climate change on wind power production are difficult to quantify as changes are extremely difficult to assess.

Changes in cloudiness that result from humidity changes may also affect the production potential of photo-voltaic (PV) cells. Given that production can be reduced to as little as 5% under cloudy conditions, increased cloud cover could be detrimental.

4.4 Overall Sensitivity

The sensitivity of generation to climate change depends very much on the mix of technologies used in a given system. Using Thailand as an example, Figure 5 shows the generation mix expected from the present up to 2017. This shows that the current dominance of fossil fuels will wane and by 2017 a third of production is anticipated from renewable plant. There would appear to be potentially more scope for supply difficulties where renewable technologies have been shown to be sensitive to climate variables.

5. Climate Impacts on Transmission

Atmospheric conditions affect the power flow rating of transmission and distribution lines and are traditionally specified by national or international standards such as those published by the IEEE [14]. The thermal rating of a line is governed by a maximum allowable conductor temperature in order to prevent excessive sagging. The conductor temperature is influenced not only by the ohmic heating effect but also ambient temperature, isolation and wind speed, of which temperature is the dominant climatic variable. Hence higher temperatures will tend to reduce transmission capacity, worsening existing network constraints and necessitating load curtailment or expensive network upgrades.

Extreme weather is also problematic for transmission systems: high winds, heavy rain and lightning can all create faults on the system. The management of these requires investment [15]. Extremely cold conditions can also create problems to which the Canadian ice storms of 2000 are testament. With an expectation of a greater frequency and intensity of extreme weather there is the potential for greater damage to the system and consequent supply interruptions.

6. Impacts on Electricity Demand

The potential impact of future changes in climate on electricity demand can be seen on a daily basis through the fluctuation of demand with weather conditions. In liberalised systems such as the UK, suppliers must accurately predict weather conditions in order to manage their supply contacts. Where they fail to do so, they are exposed to significant imbalance penalties. As such, it is area that is receiving much research attention (e.g. [16]) and has spawned interest in financial market derived techniques such as weather derivatives. As electricity demand globally is expected to grow by at least 5% by 2015 [17] and, as climate change becomes more prevalent, it will be essential for those charged with managing demand to take account of future changes.

Electricity demand is influenced not only by temperature but also wind speed, humidity, precipitation and cloud cover. These influence demand for air-conditioning, space heating, refrigeration and water pumping loads which will add to both peak and 24-hour demand. The peak loading is particularly important as on occasions of extreme temperatures this is likely to stress electricity systems in meeting demand. Again, France in 2003 is a good example of conditions where extremely hot temperatures gave rise to a significant increase in air-conditioning – at the very time that output from nuclear stations was limited by cooling limitations – threatening blackouts.

The impact on other uses of electricity can be significant: water-pumping requirements will increase where the climate change becomes warmer but not wetter as water demand from irrigation, residential, commercial and municipal sectors will rise. Refrigeration requirements would increase and water-heating requirements would decrease, although the direct effects are likely to be significantly less than the effects on space conditioning. Refrigeration and water-heating equipment is often located in conditioned spaces and thus are not affected by outdoor temperature changes. Additionally, refrigeration equipment evaporator coil temperatures are lower than those of air conditioning equipment and water heaters operate significantly hotter than room temperatures, the proportionate impact will be lower.

The impacts on electricity demand also depend on the mix of resources used for heating and cooling. If air conditioning is produced using electricity but space heating is provided by gas boilers, then global warming will increase electricity demand but overall energy use could decrease.

Clearly the degree to which electricity demand in a given country might be sensitive to changes in climate will depend very much on its climate type and its level of economic development. In high latitude countries like the UK, warmer climates will tend to reduce space heating demand. In lower latitudes cooling loads will increase with, for example, South East Asian electricity demand expected to increase by 5 to 10% [5] as a result.

Figure 6 shows the current breakdown between various uses of electricity in the domestic sector in Thailand. With its hot, humid climate, a major portion of domestic electricity use (39%) is for cooling food or accommodation. This portion would be expected to increase as Thailand’s economy grows more affluent.

While figures are not available for how Thai domestic demand might change with climate change, we can extract some information from projections for the UK (Figure 7) and from projections of Thai peak demand over the next 15-20 years (Figure 8). At present, the UK has little domestic air-conditioning load hence it is not represented in Figure 7. However, this is expected to rise although the increase will depend on complex sociological factors and is difficult to project. An indication of the potential increase is highlighted in the commercial sector which has seen 5% growth in the last five years and expects to see a further 6% rise to 2010 [15]. The rise in refrigeration usage is, however, fairly clear. Figure 8 shows a projection of peak demand in Thailand. Apart from the marked increase in overall demand levels it is clear that summer peak demand rises proportionately more. This reflects increasing economic development and a likely corresponding use of air-conditioning equipment.

7. Discussion

As the previous sections indicate, there are many areas of the electricity supply industry that are sensitive to the variability of the weather. Pre-deregulation, utilities managed weather effects through vertical integration and either absorbing costs within the organisation as a whole or, where possible, passing them on to consumers.

With deregulation, individual market players are exposed to weather effects. With an increasing emphasis on risk analysis and management, players are increasingly looking for ways to minimise or eradicate weather effects from their revenue and cost streams. These include improved forecasting techniques or risk transfer through insurance or in weather markets.

In the long term, climate change will necessitate similar approaches in analysing, planning and financing future investment in generation, transmission and demand. However, the commonly used assumption that the future will be similar to the past does not hold. As such, new techniques need to be developed and implemented that can take account of future climate uncertainty.

To this end, future work will be addressing several aspects of potential climate impacts that are particularly relevant for developing nations in South East Asia. These are likely to include:

- analysis of future demand patterns, and
- analysis of future generation availability given an increasing input from renewable resources.

8. Conclusion

This paper reviews the basis for climate change and the projections for South East Asia. It details a range of generating technologies that are sensitive to weather conditions and, in the long-term, vulnerable to changes in climate. Impacts include changes in the availability and timing of resources, impacts on conversion efficiency and variations in the economics of plant. Transmission systems are also found to be sensitive through thermal constraints and faults caused by extreme weather conditions. Demand levels are also weather-dependent as UK experience indicates.

Variations in weather and climate pose potentially serious challenges to many areas of the electricity supply industry. With deregulation, players are becoming more exposed to variations. Accordingly, they must assess the uncertainty surrounding both short and long term variations, examine the impacts and plan and manage them effectively.

Acknowledgements

The authors wish to thank the Energy Policy and Planning Office (EPPO) and Electricity Generating Authority of Thailand (EGAT) for providing data on domestic electricity demand. The first author is grateful for the financial support of EPPO through the award of a Ph.D. Scholarship.

References

[1] University of Texas, http://www.geo.utexas.edu/courses/302c/W_and_C.htm.
[2] McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; Dokken D.J.; and White K.S. (Eds.). 2001. *Climate Change 2001 Impacts, Adaptation and Vulnerability*. Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
[3] Houghton, J.T.; Jenkins, G.J.; and Ephraums, J.J. (Eds.). 1990. *Climate Change The IPCC Scientific Assessment*, Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
[4] Houghton, J.T.; Ding, Y.; Griggs, D.J.; Nogeur, M.; van der Linden, P.J.; Dai, X.; Maskell K.; and Johnson C.A. (Eds.). 2001. *Climate Change 2001 the Scientific Basis*. Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
[5] Lal, M.; Harasawa H.; and Murdiyarso, D. 2001. Asia. In *Climate Change 2001 Impacts, Adaptation and Vulnerability*. McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; Dokken D.J.; and White K.S. (Eds.). Cambridge: Cambridge University Press, Chap. 11.
[6] Stern. F. 1998. Energy. In Feenstra, J.F.; Burton. L.; Smith, J.B.; and Tol, R.S.J. (Eds.). In *Handbook on methods for climate change impact assessment and adaptation strategies*. United Nations Environment Programme, Vrije Universiteit Amsterdam, Institute for Environmental Studies.
[7] Reibsame, W.E.; Strzepek, K.M.; Wescoat Jr., J.L.; Perritt, R.; Gaile, G.L.; Jacobs, J.; Leichenko, R.; Magadza, C.; Phien, T.; Urbiztondo, B.J.; Restrepo, P.; Rose, W.R.; Saleh, M.; Ti, L.C.; Tucci, T and Yates, D. 1995. Complex River Basins. In *As Climate Changes: International Impacts and Implications*. Strzepek, K.M. and Smith, J.B. (Eds.). Cambridge: Cambridge University Press.
[8] Moreno, R.A. and Skea, J. 1996. Industry, Energy and Transportation: Impacts and Adaption. *In Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis*. Watson, R.T.; Zinyowera, M.C.; and Moss, R.H. New York: Cambridge University Press.
[9] Harrison, G. P. and Whittington, H. W. 2002. Vulnerability of hydropower projects to climate change. IEE *Proc. Generation, Transmission & Distribution*, 149(3): 249-255.
[10] Harrison, G. P.; Whittington, H. W.; and Wallace, A. R. In review. Sensitivity of hydropower performance to climate change. *International Journal of Power and Energy Systems*.
[11] Harrison, G. P.; Whittington, H. W.; and Wallace, A. R. 2003. Climate change impacts on financial risk in hydropower projects. *IEEE Trans. Power Systems*, 18(4):.
[12] Bogardi, I. and Matyasovszky, I. 1996. Estimating daily wind speed under climate change. *Solar Energy* 57(3): 239-248.
[13] Electricity Generation Authority of Thailand. 2001. *Energy*. Bangkok: EGAT.
[14] IEEE Standards Board. 1993. *IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors*. New York: IEEE.
[15] Wood, J. 2003. The effect of one degree. *IEE Power Engineer* (17)3: 6-8.
[16] Lo, K.L. and Yu, Y.K. 2003. Risk assessment due to local demand forecast uncertainty in the competitive supply industry. *IEE Proceedings Generation, Transmission & Distribution* 150(5): 573-582.
[17] IPCC. 1995. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis. Intergovernmental Panel on Climate Change. Cambridge University Press, New York.
[18] Pok, S. 2003. Personal Communication.

Tables

Table 1. SRES scenarios and the implications for CO_2 level, climate and sea level [2]

Date	Population (billions)	Global GDP (10^{12} US$/yr)	CO_2 level (ppm)	Temperature rise (ºC)	Sea level rise (cm)
1990	5.3	21	354	0	0
2000	6.1-6.2	25-28	367	0.2	2
2050	8.4-11.3	59-187	463-623	0.8-2.6	5-32
2100	7.0-15.1	197-550	478-1099	1.4-5.8	9-88

Table 2. Examples of climate change risk in South East Asia [5]

Risk in South East Asia from climate change	Confidence level
Increased vulnerability of climate-dependent sectors affecting the economy.	Medium
The large deltas and coastal low-lying areas will be inundated by sea-level rise.	High
The frequency of forest fires in will increase.	Medium
Increased precipitation intensity during the monsoon increases flood risk in temperate/tropical areas.	Medium
Drier conditions in arid/semi-arid areas during summer, leading to more severe droughts.	Medium
Climate change and variability could exacerbate existing extreme climate vulnerabilities in temperate/tropical areas.	High

Figures

List

Figure1. Historic and expected range of future temperature rise (adapted from [3, 4])

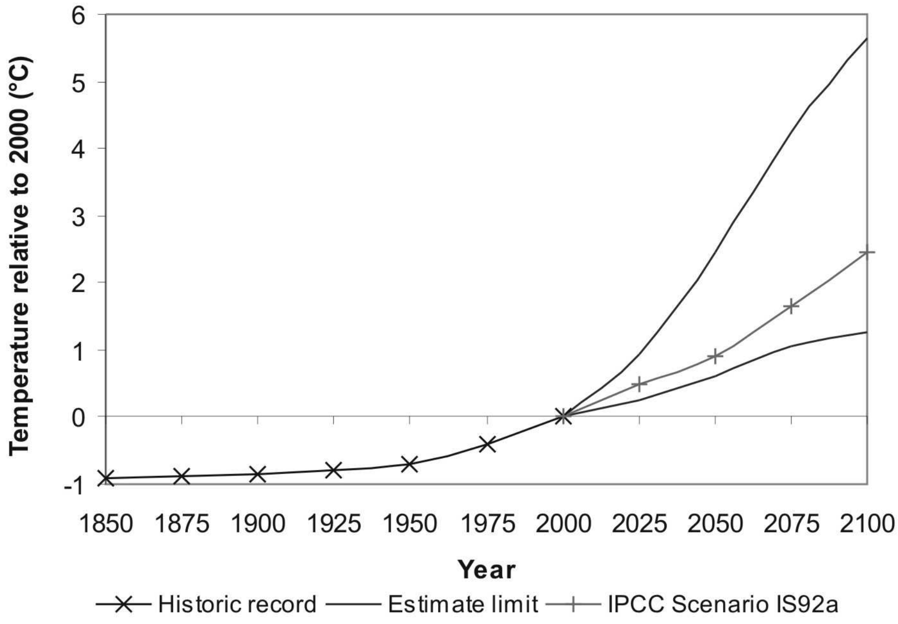

Figure 2. Plausible changes in temperature in tropical South East Asia [5]

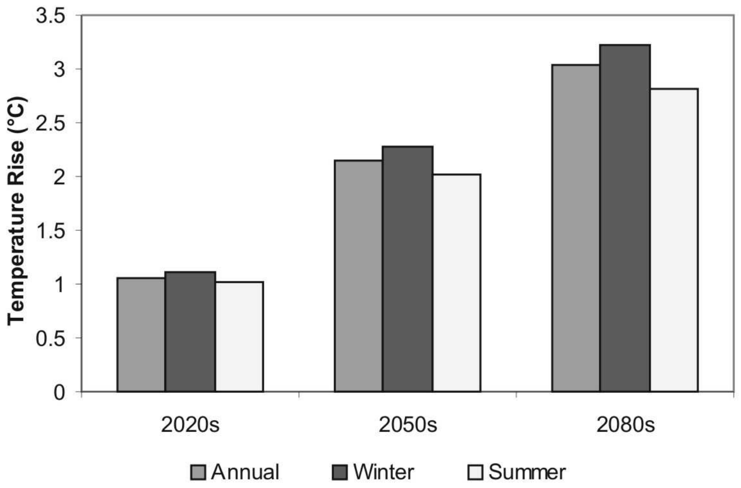

Figure 3. Plausible changes in precipitation in tropical South East Asia [5]

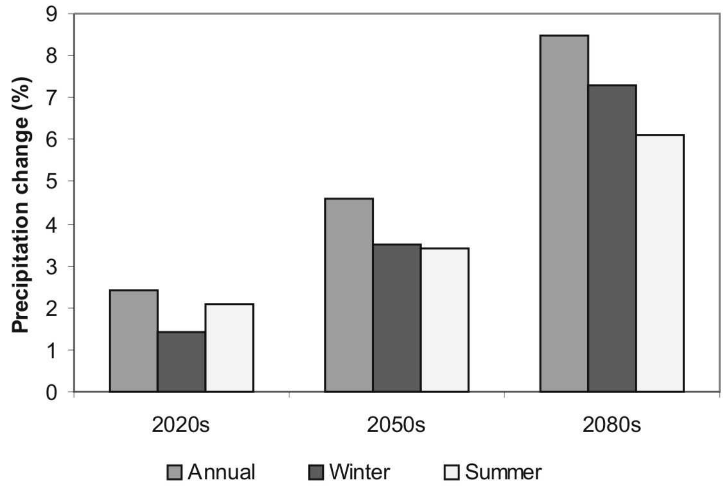

Figure 4. Historic (Base) and projected river flows at location in Lower Mekong Basin for Hadley Centre scenario (adapted from [7])

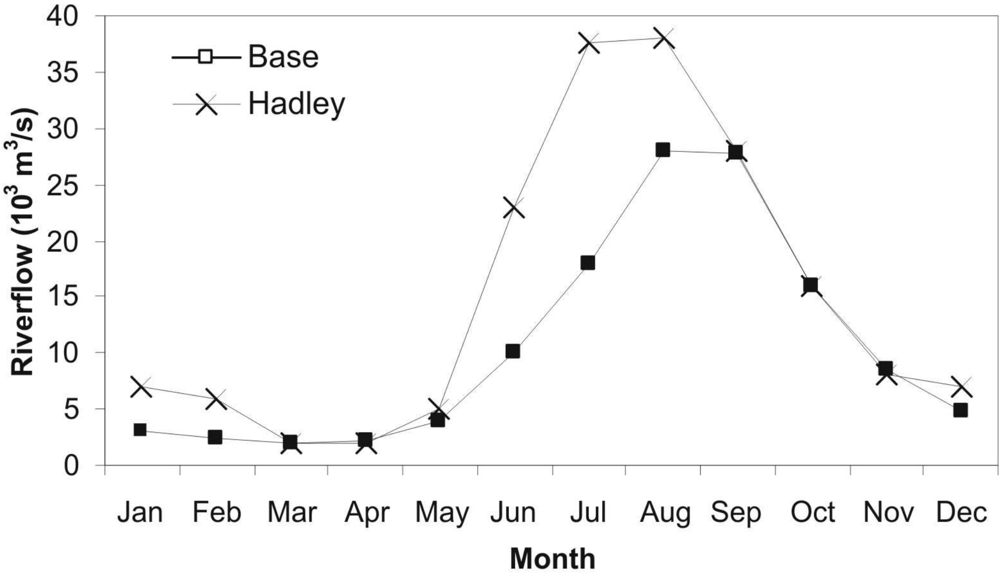

Figure 5. Forecast generation fuel mix in Thailand to 2017 [13]

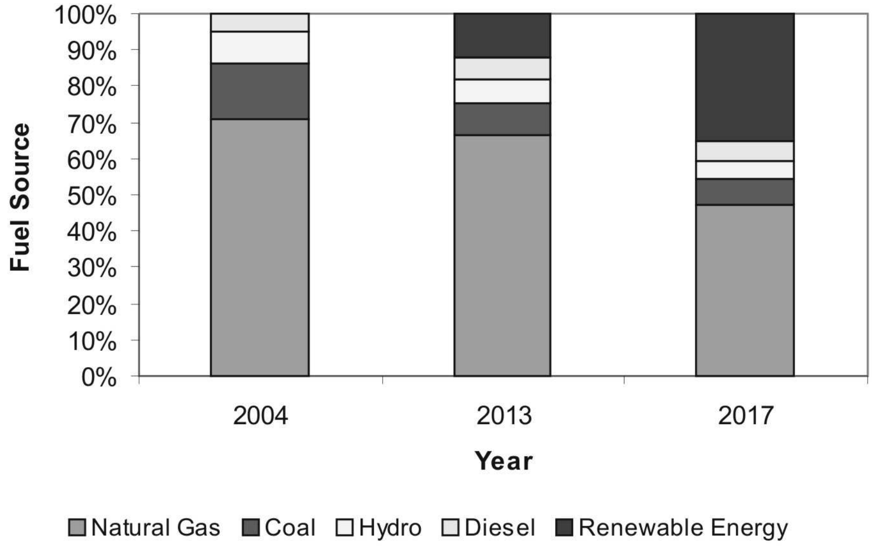

Figure 6: Thai domestic electricity demand in 2003 [18]

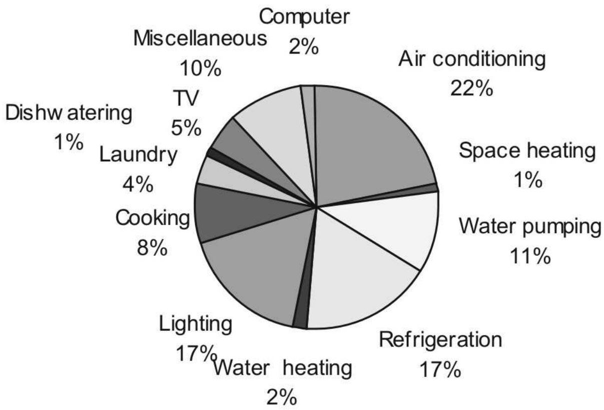

Figure 7. UK domestic electricity demand in 1997 and forecast for 2020 [15]

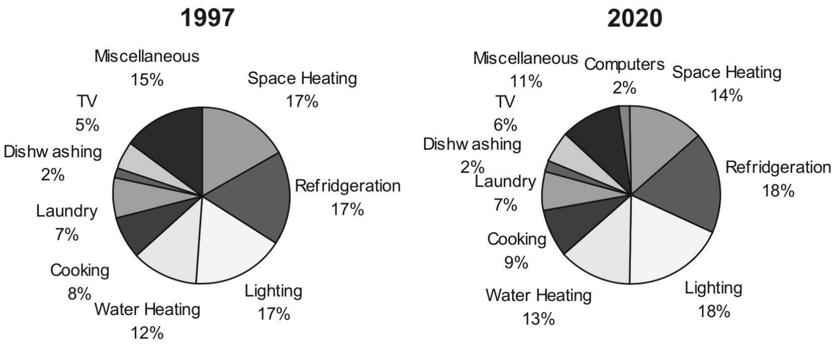

Figure 8. Maximum electricity demand curves for Thailand [13]